U.S. Army Evaluation Center

Reliability, Availability, and Maintainability (RAM) Evaluation of Unmanned Aircraft Systems (UAS)

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Purpose

- Provide 3 examples of how the reliability, availability, and maintainability (RAM) for multi-component Unmanned Aircraft Systems (UAS) may be evaluated.

- Present challenges that are faced and how they may be resolved.

Agenda

- Unmanned Aircraft Systems (UAS) and Reliability, Availability, and Maintainability (RAM) Defined
- Launcher UAS Example
  - Failure Mode Plot
- Hand-Launched UAS Example
  - Reliability Growth Curve
- Standard Takeoff UAS Example
  - Modeling and Simulation
- Challenges
- Concluding Remarks

The Problem

- The Army is relying more on unmanned platforms
  - Need reliable systems
- How do we determine if the system can perform 24 hour continuous operations while supporting multiple missions?

Unmanned Aircraft Systems

- Complex systems with multiple components that rely on each other to complete the mission.
  - A Ground Control Station (GCS) is needed to fly the Unmanned Aircraft (UA) and to control the sensor packages and weapons systems.
- All of these have their own reliability and maintainability which affect the overall system availability.

RAM Defined

- Reliability quantifies the likelihood for the UAS to successfully operate under designated operating conditions for a specified period of time.
- Maintainability quantifies the likelihood for the UAS to be restored or repaired to a specified operational condition within a period of time when maintenance is performed in accordance with prescribed procedures.
- Availability quantifies the fraction of time the UAS successfully sustains operations under stated conditions and in an ideal support environment, i.e., ideal spare part availability, ideal operators, ideal diagnostics equipment, ideal troubleshooting,

Launcher UAS Example

- System Description:
  - 4 Unmanned Aircraft (UA)
  - 2 Ground Control Stations (GCS)
  - Multiple Payloads
  - Launcher
  - 2 Ground Data Terminals (GDT)
  - 4 Remote Video Terminals (RVT)
- MTBSA, MTTR, and Ao all at System Level
- 1 Mission at a time

- Issue: How do we determine total operating time?
  - Resolution: The total operating time is defined as when the entire system is operational. The UA, GCS, and sensors all have to be operational when flying, therefore flight time is used.

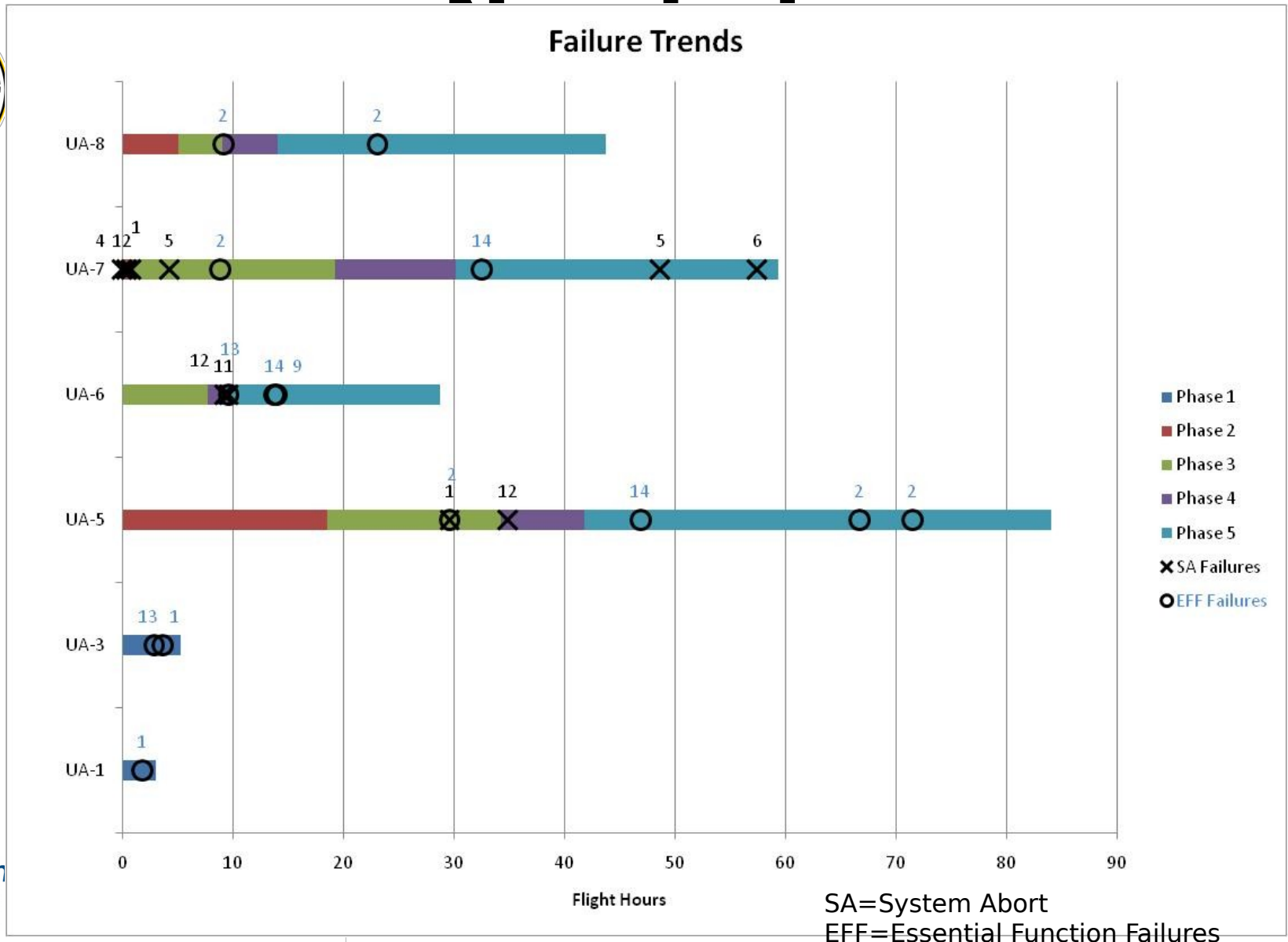
Launcher UAS Results Example

- Inputs:
  - Flight Time = 200 hours
  - Number of System Aborts (SA)= 14
  - Total Unscheduled Maintenance Time = 8 hours
  - Administrative Logistics Down Time (ALDT) (as determined = 4 hours
- Outputs:
  - MTBSA = 200 hours/14 SAs = 14 hours
  - MTTR = 7 hours/14 SAs = 0.5 hour
  - Ao = MTBSA/ (MTBSA + MTTR + = (14+0.5+4) = 0.76

All of these values are for example only and do not represent a specific system or test.

MTBSA = Mean Time Between System Abort
MTTR=Mean Time to Repair, Ao = Operational Availability

Further Analysis



SA=System Abort
EFF=Essential Function Failures

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Is This Data Really Combinable?

Comparison of Two or More Exponential Means for Time Terminated Tests
Chi-Square Approximate Method
Maximum Number Tests (Samples) = 20

	INPUT		OUTPUT
	SAMPLE i	TEST TIME Ti	NUMBER FAILURES Fi	CHI-SQUARE
	1	8	2	3.768741
	2	24	3	1.074081
	3	25	2	0.041245
	4	25	4	2.966959
	5	120	3	3.398975
TOTALS	5	202	14	11.25

Ho: Means of the Populations are Equal
H1: Means of the Populations are not Equal

Total Number of Samples =	5
Total Test Time =	202
Total Number of Failures =	14
Chi-Square Statistic =	11.250
p - value =	0.0239

Decision: Reject Ho if the p-value is less than or equal to the desired level of significance.

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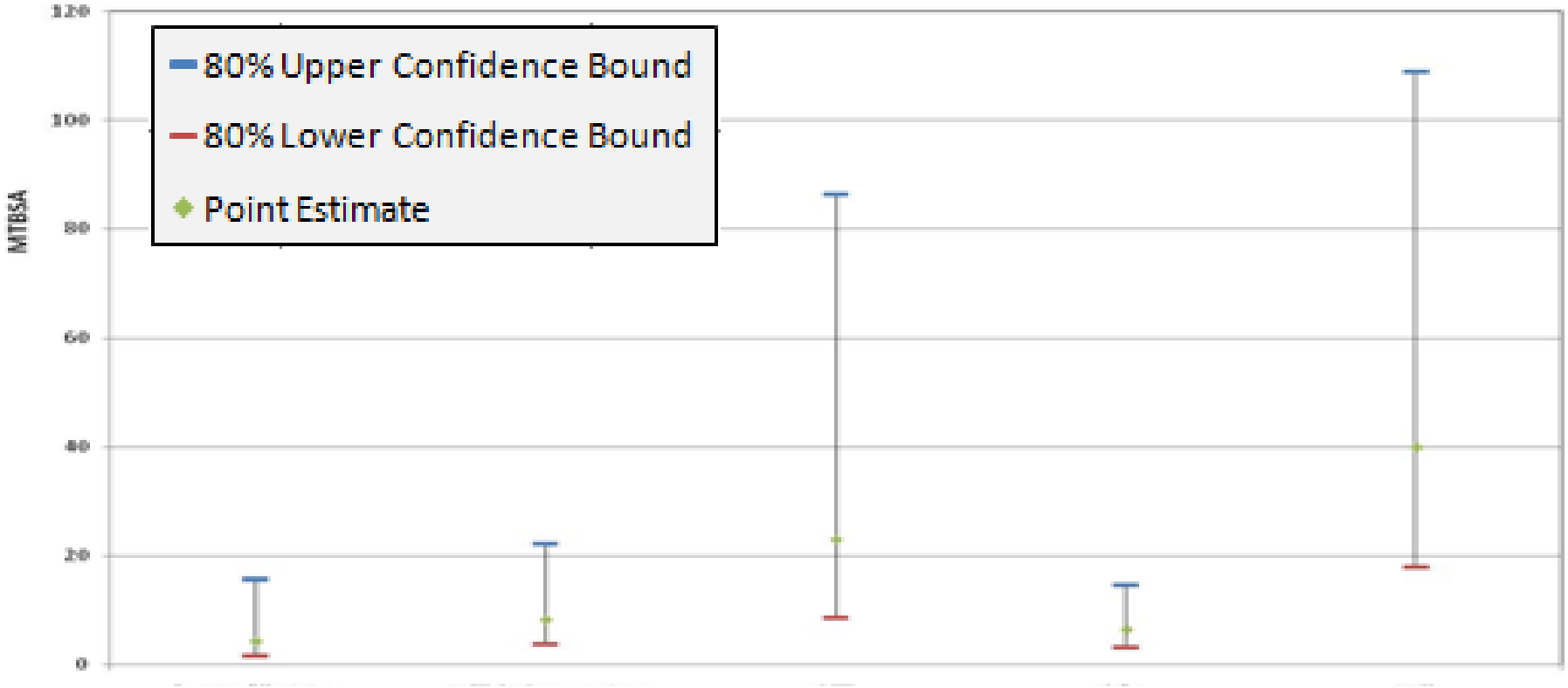
No!

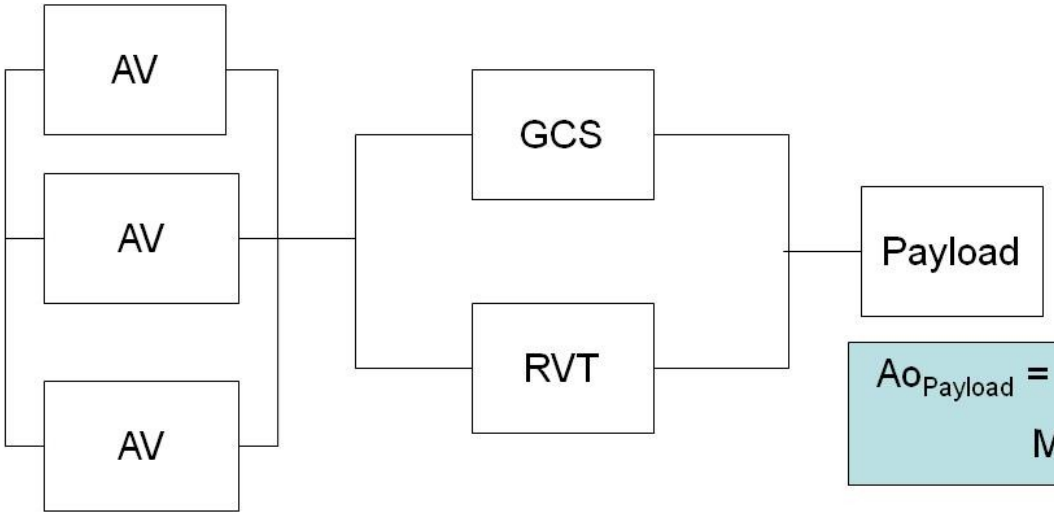
Mean Comparison



Hand-Launched UAS Example

- System Description:
  - 3 UA (hand-launched)
  - 1 GCS
  - 1 RVT
  - 2 Types of Payloads
- MTBSA and MTTR on each Subsystem. Ao at system level.
- Issue: How do we determine the Overall Ao based on the subsystem MTBSA and MTTR?
  - Resolution: Use a reliability block diagram and make assumptions.

Hand-Launched UAS Evaluation



Mean Down Time (MDT) MDT = MTTR + ALDT

$$Ao_{Payload} = \frac{MTBSA}{MTBSA+MDT}$$

$$Ao_{GCS\&RVT} = Ao_{GCS} + Ao_{RVT} - (Ao_{GCS} * Ao_{RVT})$$

$$Ao_{3AV} = \frac{MTBSA^3 + (MTBSA^2 * MDT) + (MTBSA * MDT^2)}{MTBSA^3 + (MTBSA^2 * MDT) + (MTBSA * MDT^2) + MDT^3}$$

$$Ao_{System} = Ao_{3AV} * Ao_{GCS\&RVT} * Ao_{Payload}$$

Assumptions:

1 AV Operating with 2 Spares that can be immediately launched.

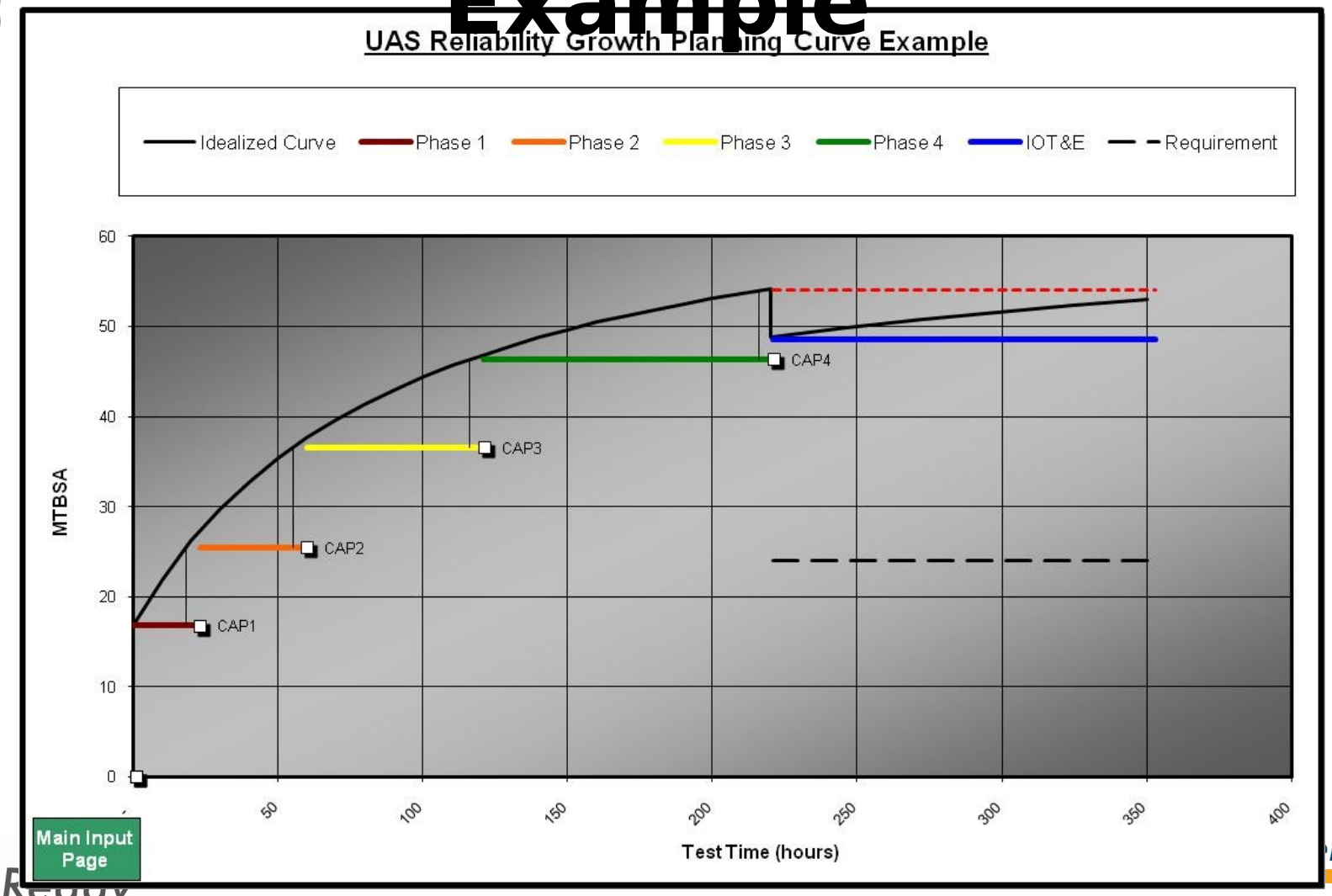
Both GCS and RVT are operating at start of mission.

AV=Air Vehicle

Reliability Planning

- Since the availability relies heavily on the reliability, it is imperative that the reliability requirements are met.
- Reliability Planning is very important (and required for most systems).
  - Do you have enough test time to find failure modes and demonstrate the requirement?
  - Are there enough Corrective Action Periods and are they long enough to implement fixes?

Reliability Growth Curve Example



Standard Takeoff UAS Example

- System Description:
  - 12 UA
  - 5 GCS
  - 2 Types of Multi-Mission Payloads
  - Weapons Systems
- Ao (KPP) defined as ability to support 3 simultaneous 24 hour continuous missions.
- MTBSA & MTTR for each subsystem must support system-level Ao.
- Multiple UA Configurations.

- Issue: How do we calculate the Overall System Ao and Each Mission Ao?
  - Resolution: Develop a model using the reliability and maintainability for each subsystem as inputs.

Now what?

- Thoroughly review the requirements documents, Operational Mode Summary/Mission Profile (OMS/MP), Concept of Operations (CONOPS), and Failure Definition/Scoring Criteria (FDSC).

- Get the RAM Working Group (WG) together and develop a model.
  - Make sure that those with the answers are in attendance.

Challenge 1: What is a Subsystem Abort?

- Anytime that subsystem cannot complete the mission. Examples:
  - GCS fails requiring another GCS to take over.
  - UA cannot takeoff and a replacements UA is flown.
  - UA has to Return to Base (RTB) due to UA, sensor package or weapons system failure.
  - Interruption in UA control or information

Challenge 2: Does a Subsystem Abort Result in a Mission Abort?

- It depends:
  - How long of an interruption to the mission is acceptable?
  - What happens if a GCS goes down? Can another one take over?
  - If the sensor fails, can it be fixed while flying?
  - If the UA fails in flight, does it always require a RTB?
- These answers should come from the TCM, PM, and system contractor(s).

Challenge 3: For Continuous Ops, How is Downtime Measured?

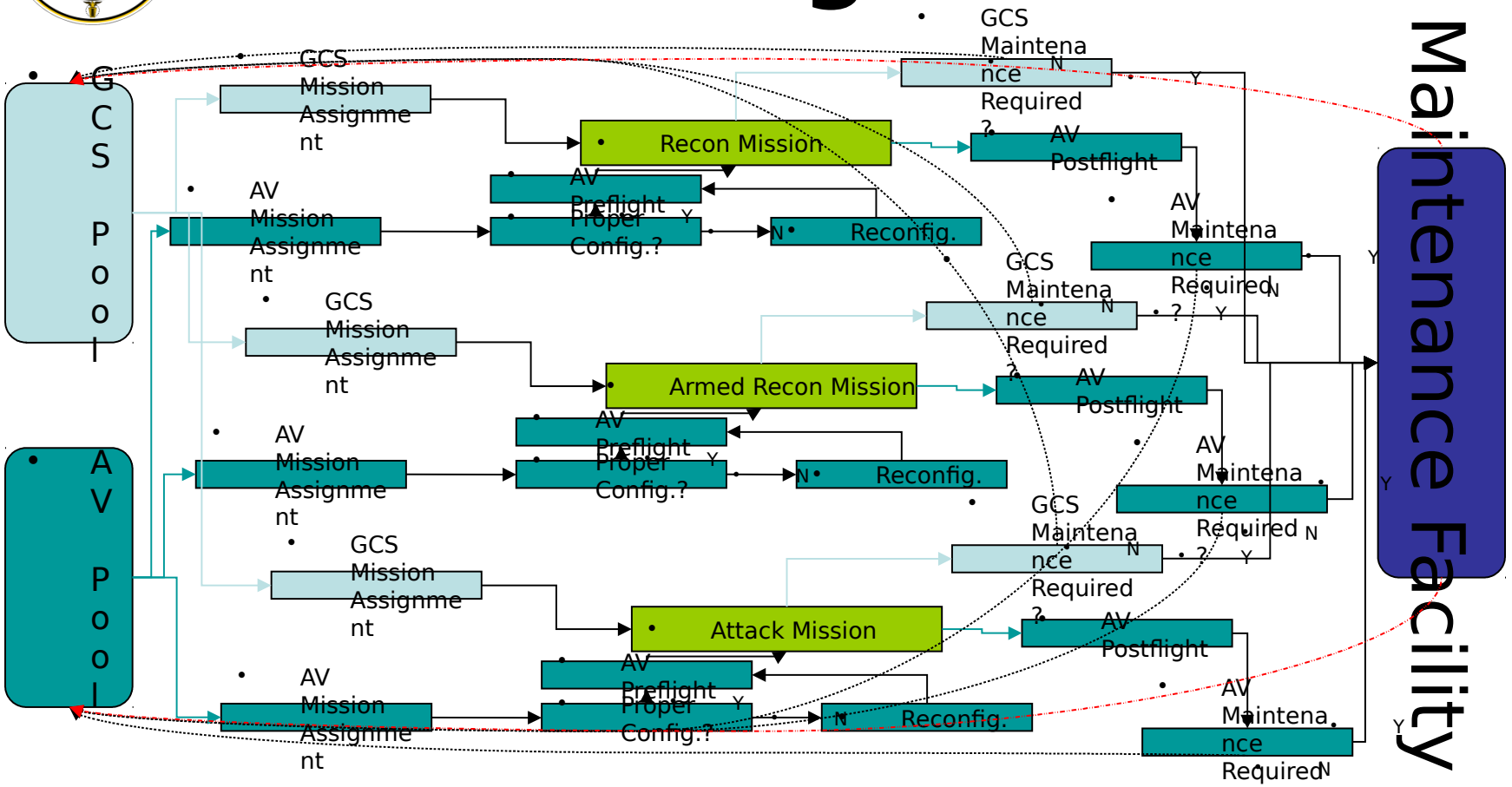
- The amount of time it takes to return to mission.
  - Examples:

Scenario	Downtime
UA Failure occurs causing the need to land.	Time to get a new UA to where the failed UA left mission.
GCS Failure, interruption in flight control or data.	Time to get GCS back on-line or a replacement to take over.
Payload Failure causing delay in data.	Time to restore payload while in flight or time to get a new UA with working payload to take place of one with malfunctioning payload.
UA, GCS, or payload being repaired or in scheduled maintenance making it unavailable to launch a new AV and continue mission.	Time it takes to restore mission functions.

Arena® M&S Tool

- Monte Carlo based Modeling & Simulation tool developed by Rockwell Automation
- Provides ability to address:
  - processes, resources, and elements of the UAS in a realistic logistics and operational environment.
- Supports analysis on the impact of the interaction of the system elements and resources in the processes assessing shortages, cueing, readiness, and other key indicators.

UAS Simplistic Model Diagram



One More Hurdle…

- Verification, Validation, and Accreditation (VV&A) of the model must be completed before it is used for an evaluation.
  - V&V activites should be done by third party.
  - ATEC is responsible for Accreditation.

Summary

- The Army is relying on Unmanned Aircraft Systems.
- We need reliable systems to perform the complex missions.
- RAM Evaluation Approach must be tailored for each system based on its mission and requirements.
  - Need to involve TCM, PM, and system contractor early to develop realistic model.
- New challenges arise with each system. Update approach when necessary.